AUGUST 15, 2017

GEORGE W ANNANDALE

SUSTAINABLE WATER SUPPLY AND CLIMATE CHANGE

USACE
Lakewood, Colorado

DAMS FOR PEOPLE

- Dams ARE for People
  - Domestic Water Supply
  - Irrigation and Food
  - Energy
  - Flood Protection
  - Recreation
  - Fisheries
  - Industrial Water Supply

THE DAM DESIGNER’S NIGHTMARE

CURRENT FOCUS OF THE PROFESSION

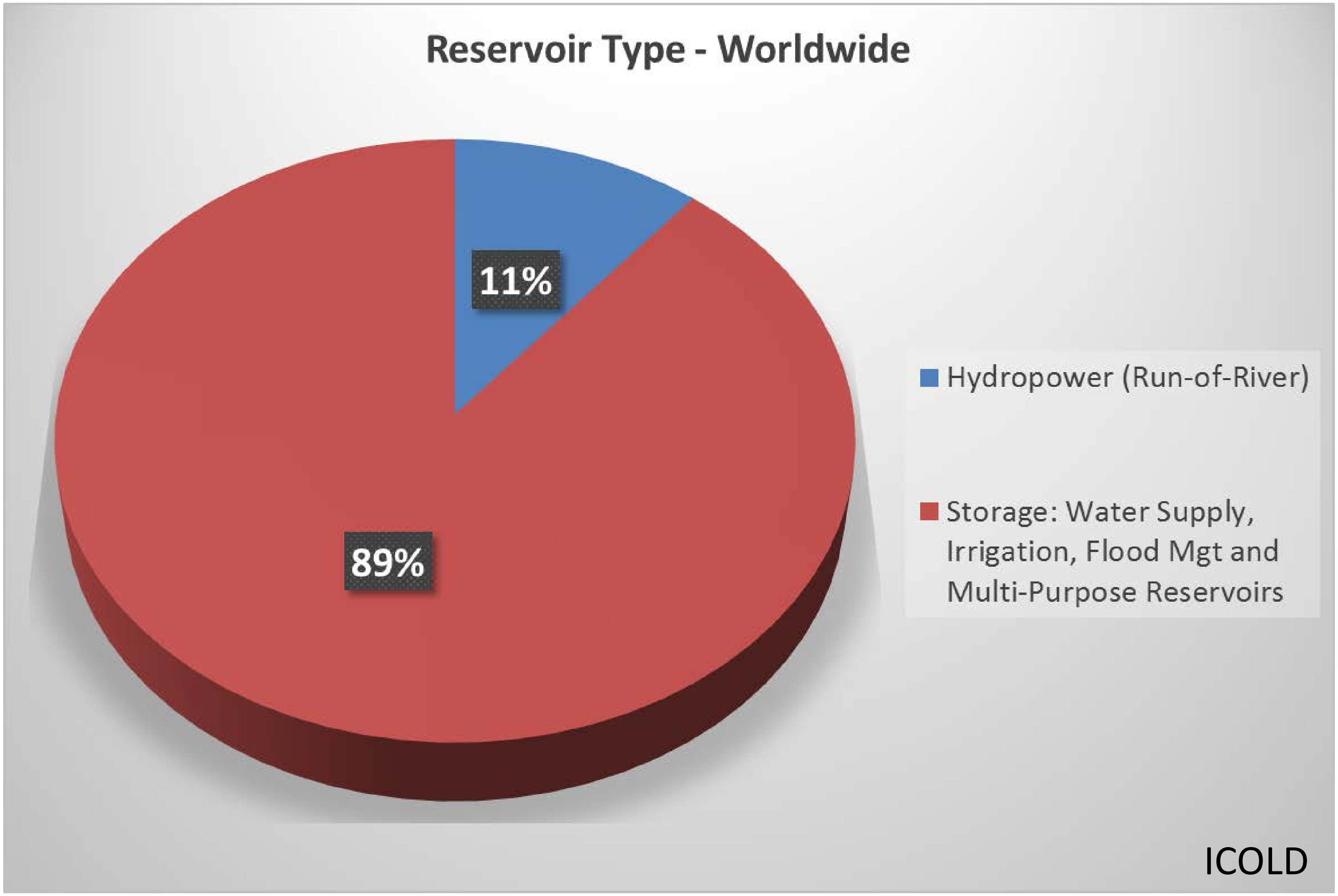
Dam Safety

It is Important

BUT

Does it ensure **SUSTAINABLE DEVELOPMENT**?

WHY DO WE BUILD DAMS?



WHAT IS SUSTAINABLE DEVELOPMENT?

"Sustainable development seeks to meet the **needs and aspirations** of the **present** without compromising the ability to meet those of the **future**"

- Brundtland Commission Report: "***Our Common Future (1987)***"

INTERGENERATIONAL EQUITY

INTERGENERATIONAL EQUITY

- Focused on FAIRNESS BETWEEN GENERATIONS
- Environmental Stabilization
  - A DESIRABLE CONSEQUENCE of Sustainable Development
  - NOT THE OBJECTIVE of Sustainable Development

SUSTAINABLE DEVELOPMENT

HOW TO SUSTAINABLY DEVELOP A RESOURCE

- RENEWABLE resources are used at a RATE that is smaller than its RATE of regeneration

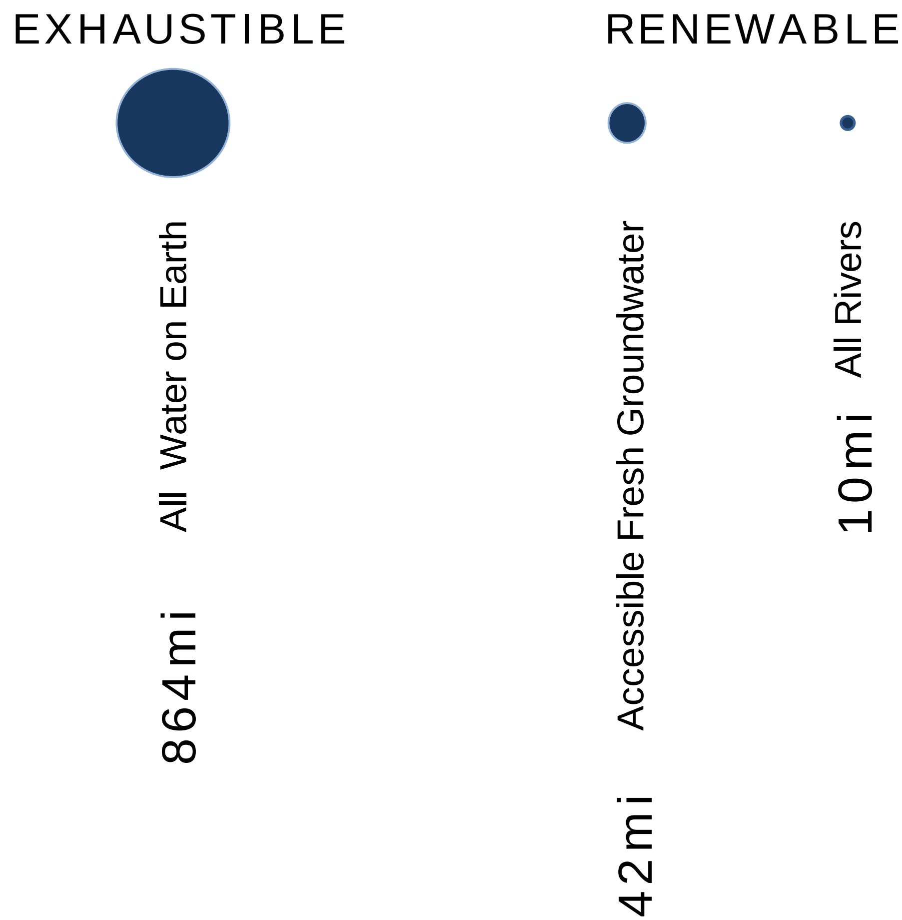
- EXHAUSTIBLE resources are used at a RATE that is smaller than the RATE of development of renewable substitutes, and

- POLLUTION does not exceed the RATE by which the environment can assimilate it.

  - Herman Daly

WATER
RENEWABLE OR EXHAUSTIBLE?

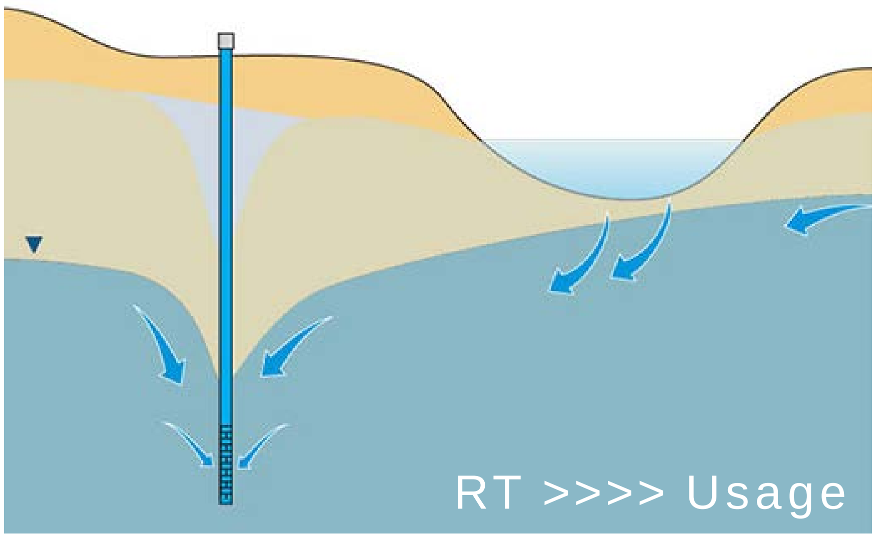
7,972mi



GROUNDWATER OR RIVER WATER?

POTENTIAL FOR SUSTAINABLE DEVELOPMENT

Daily Use of Water

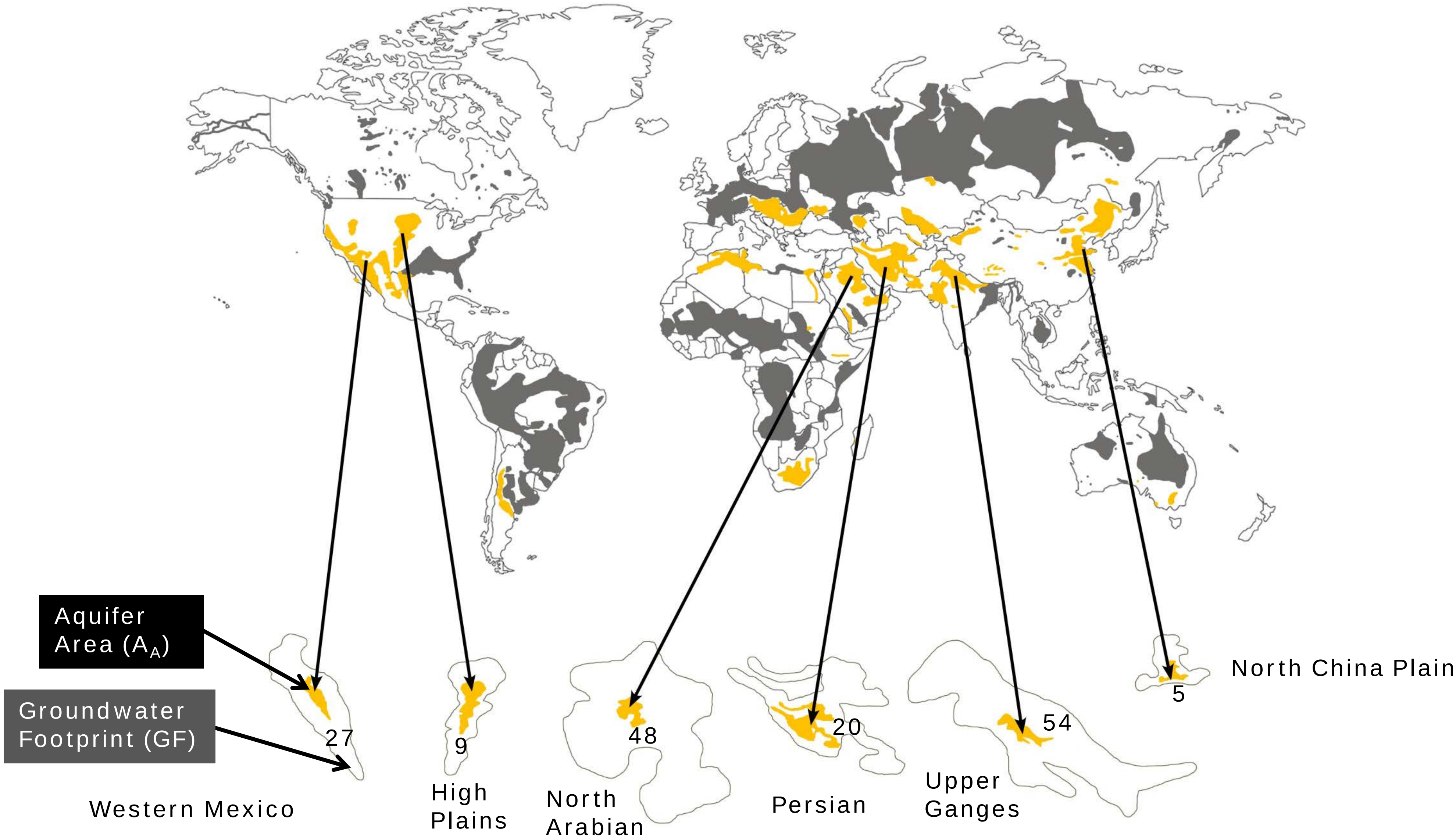


Residence Time = 1,400 years

Residence Time = 16 to 18 days

GROUNDWATER FOOTPRINT

GLOBAL FOOTPRINT = 3.5

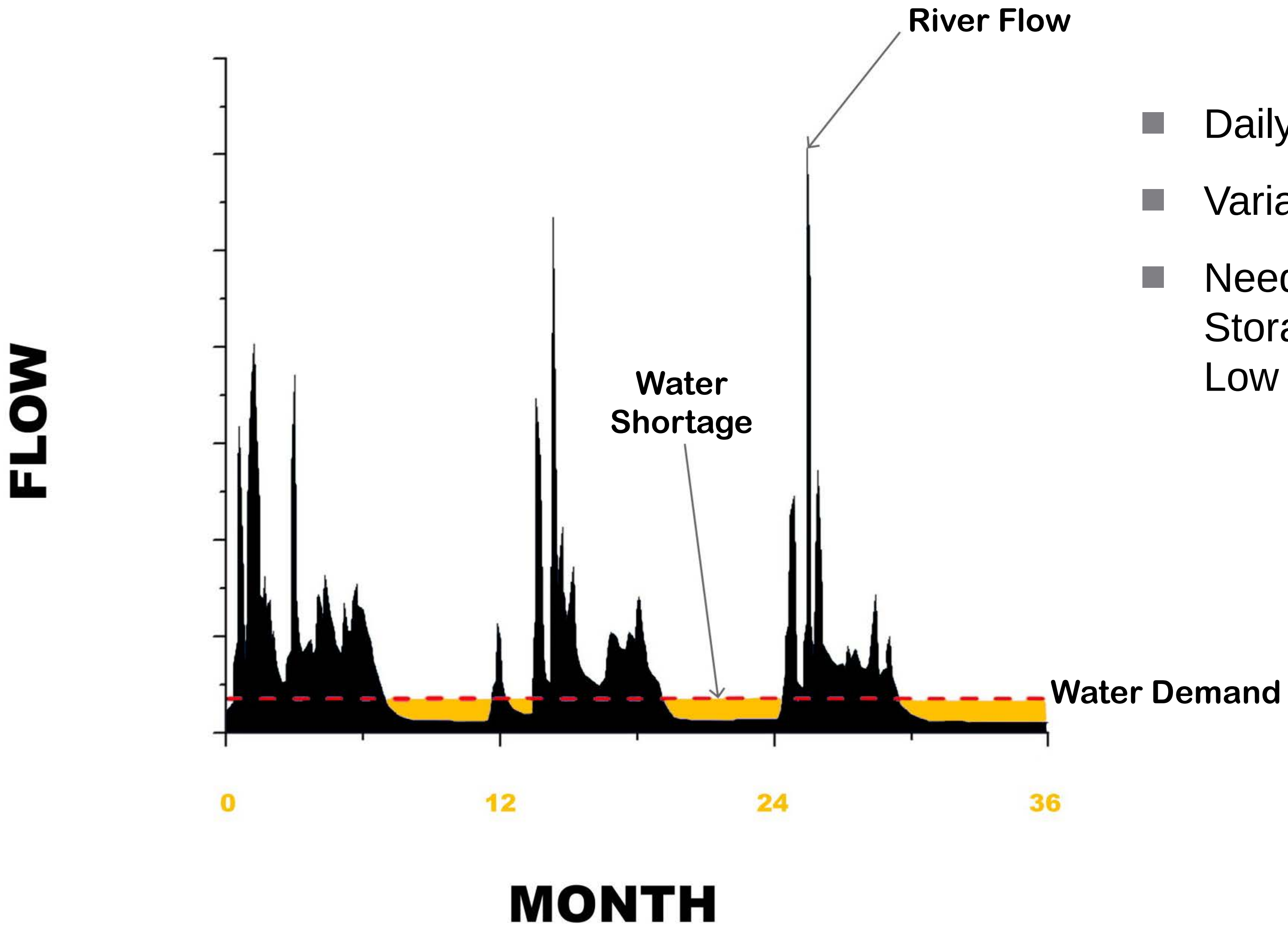


RIVER WATER

PREFERRED SOURCE OF FRESH WATER

LOW HYDROLOGIC VARIABILITY

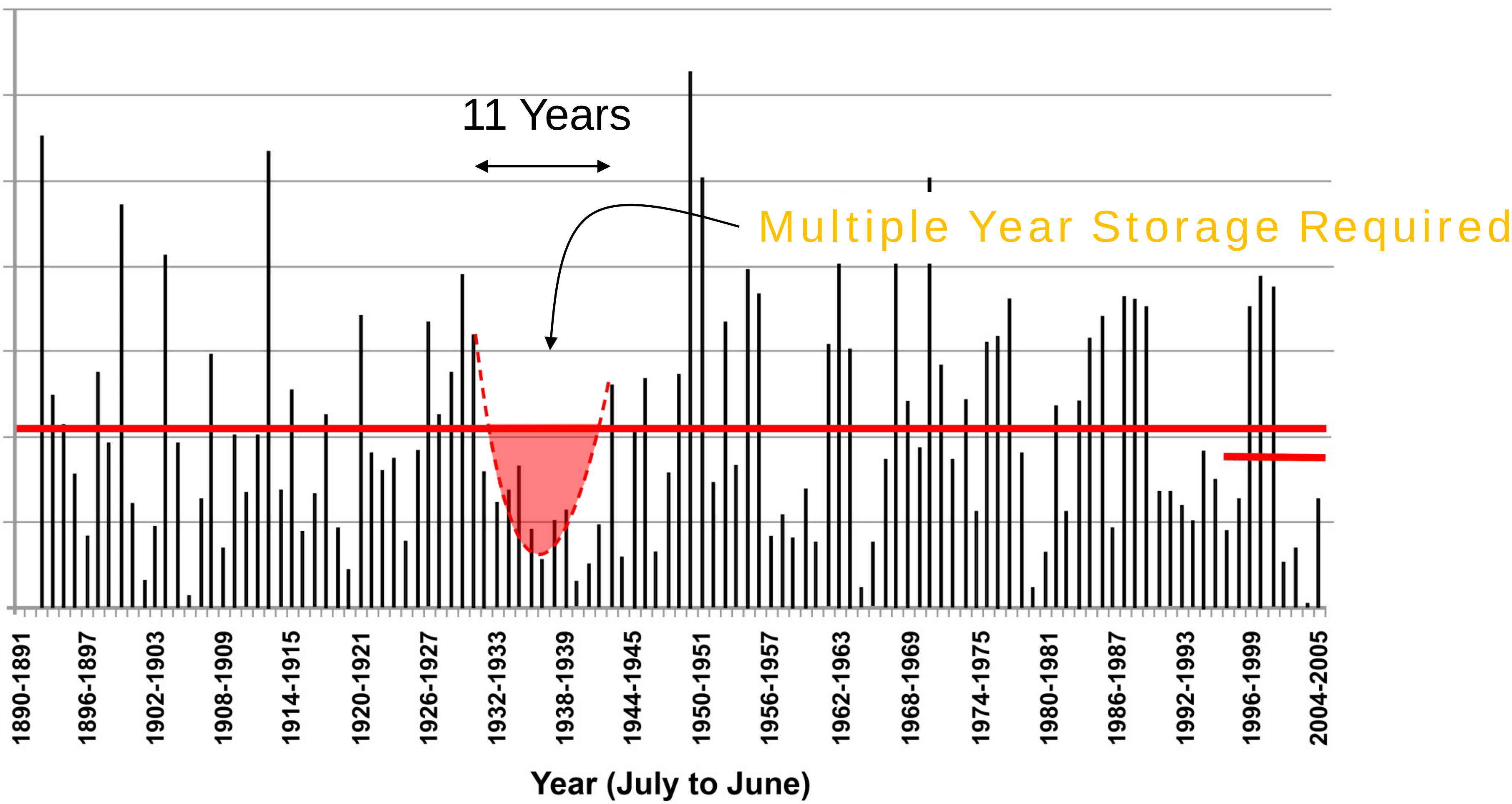
RUN-OF-RIVER SYSTEMS



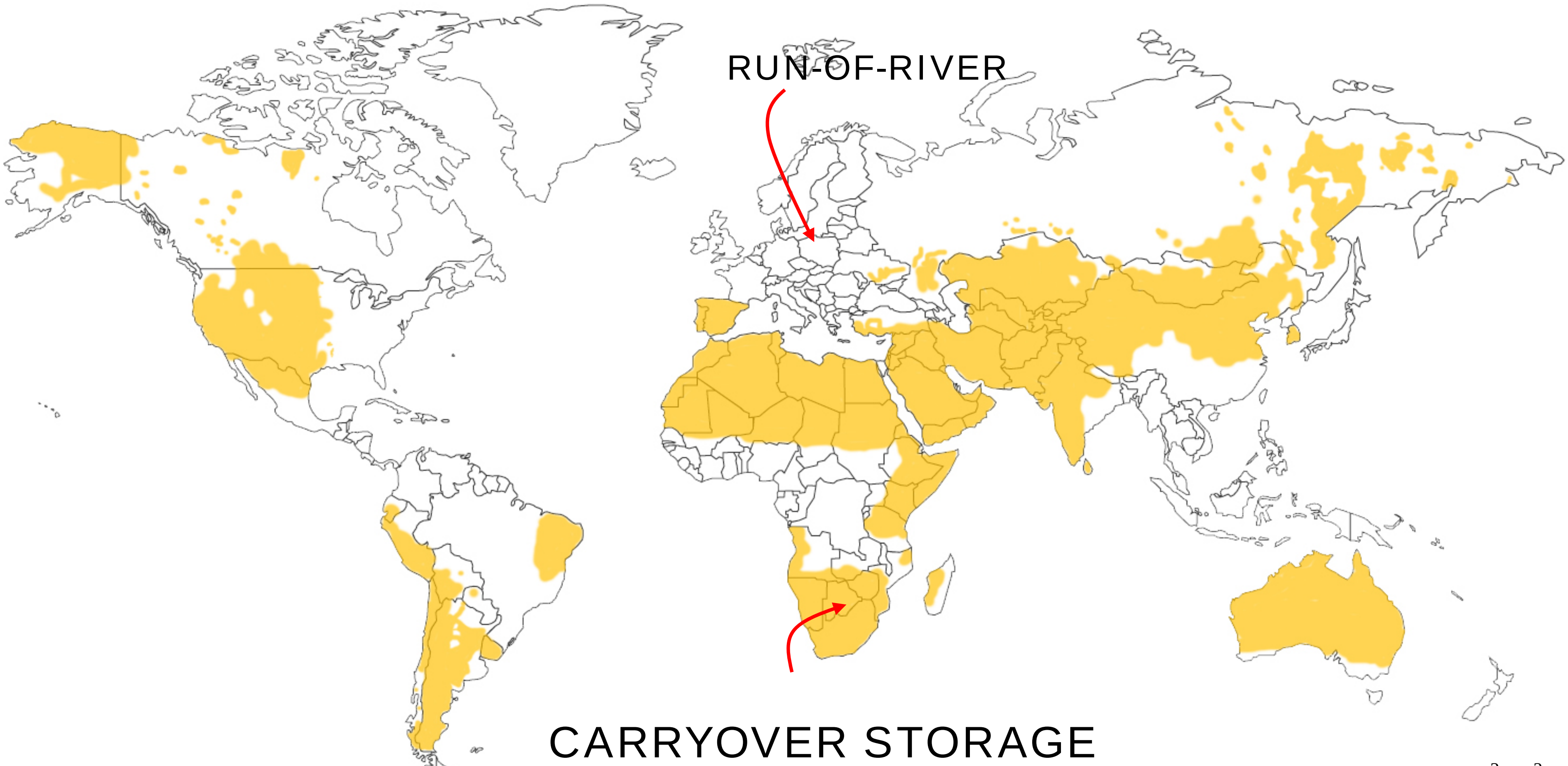
- Daily Renewal
- Variable Flow
- Need for Run-of-River Storage to Supply during Low Flow Season

HIGH HYDROLOGIC VARIABILITY

MULTIPLE YEAR DROUGHTS AND WATER SUPPLY

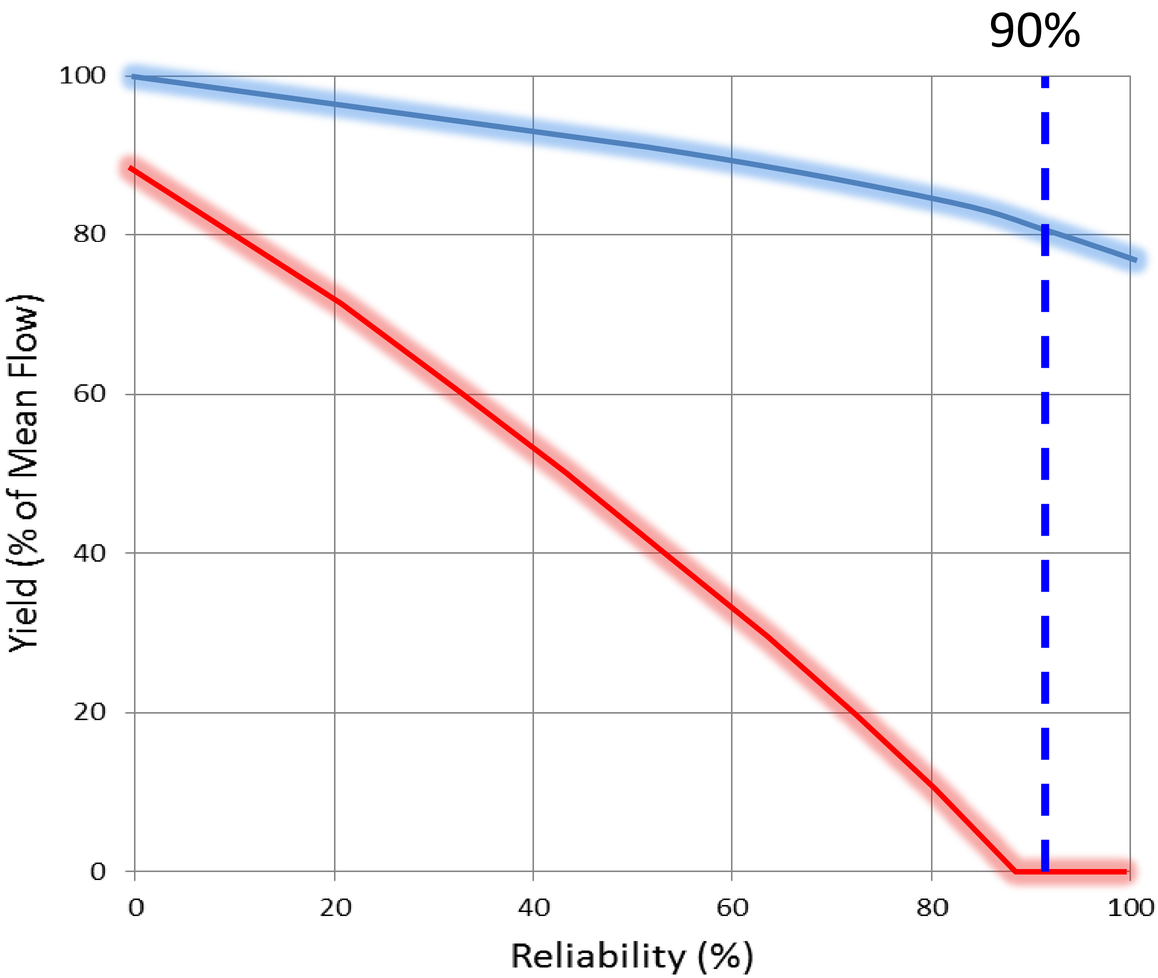


RUN-OF-RIVER AND CARRYOVER STORAGE REGIONS



$$n_{crit} = \frac{z_{\gamma}^{2} \cdot c_{v}^{2}}{4 \cdot (1-\alpha)^{2}}$$

WATER SUPPLY RELIABILITY
NO STORAGE

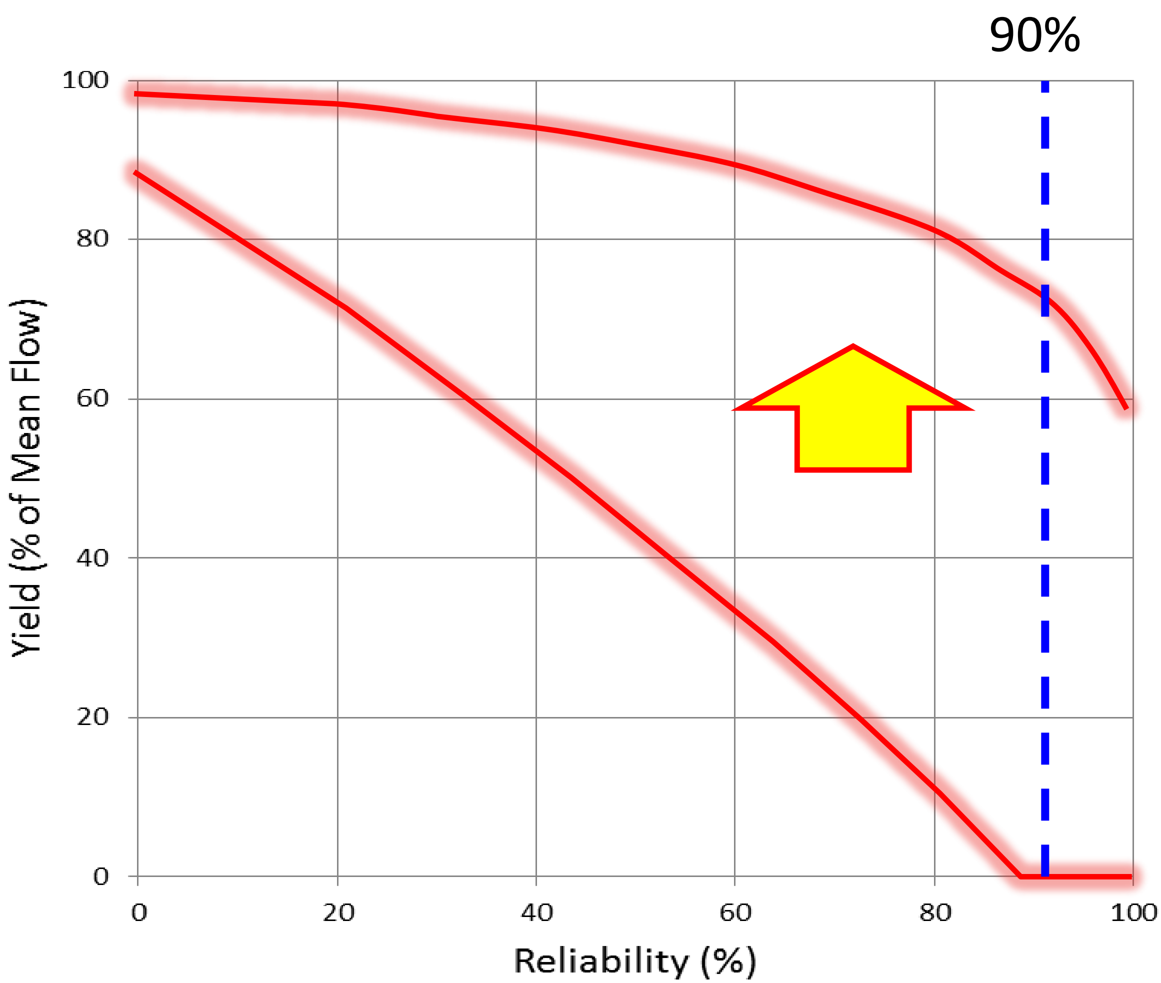


LOW VARIABILITY

HIGH VARIABILITY

$$\alpha' = 1 + c_v \cdot z_\gamma$$

WATER SUPPLY RELIABILITY
HIGH VARIABILITY WITH STORAGE



HIGH VARIABILITY

WITH STORAGE
= 1 X MEAN ANNUAL FLOW

$$\alpha = 1 - \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot \tau}$$

HIGH VARIABILITY
NO STORAGE

$$\alpha' = 1 + c_v \cdot z_\gamma$$

CLIMATE CHANGE AND WATER SUPPLY

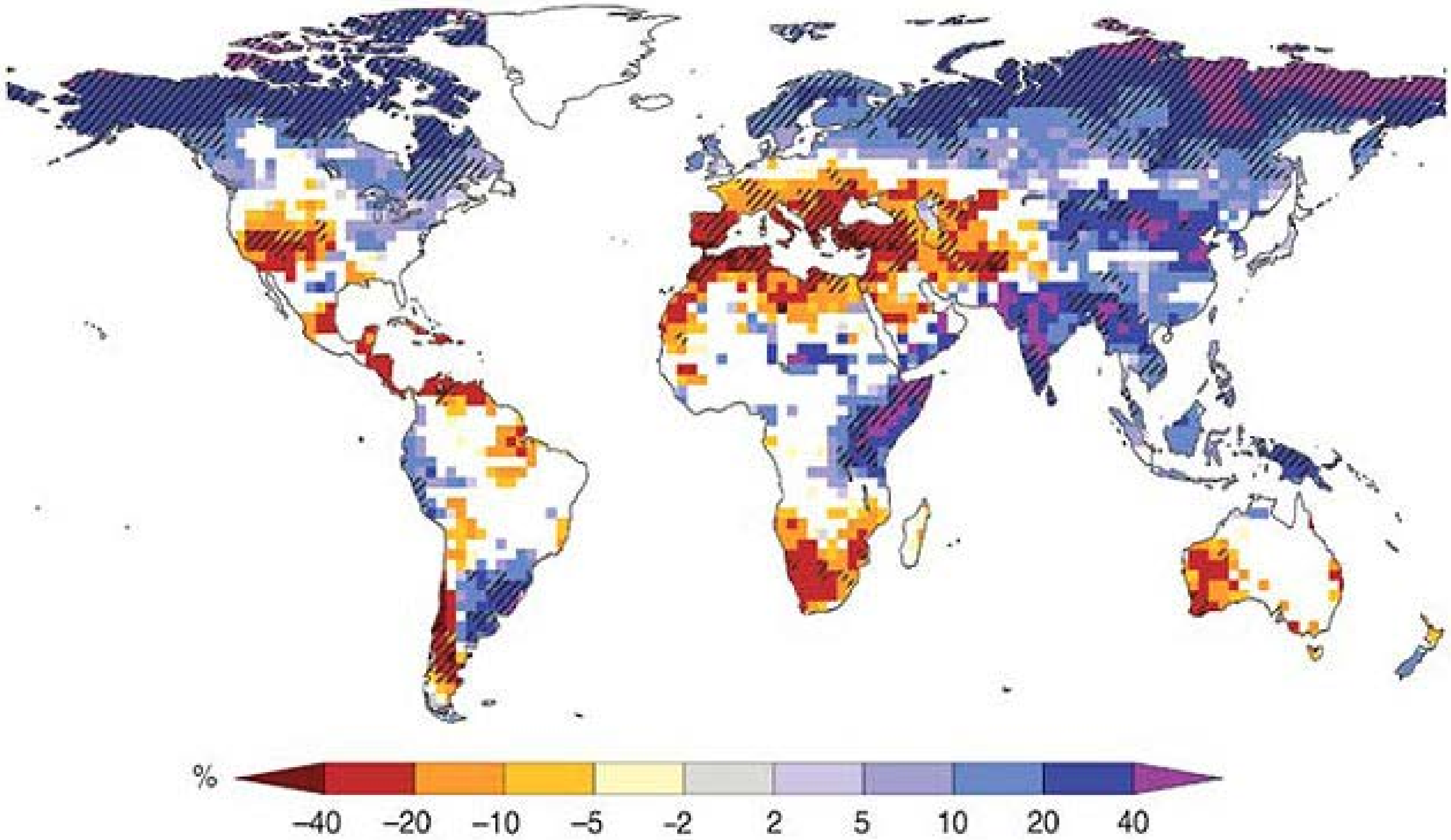
TWO IMPORTANT VARIABLES

CHANGE IN **MEAN** ANNUAL RIVER FLOW

CHANGE IN HYDROLOGIC **VARIABILITY**

CLIMATE CHANGE

MEAN ANNUAL FLOW INCREASE/DECREASE



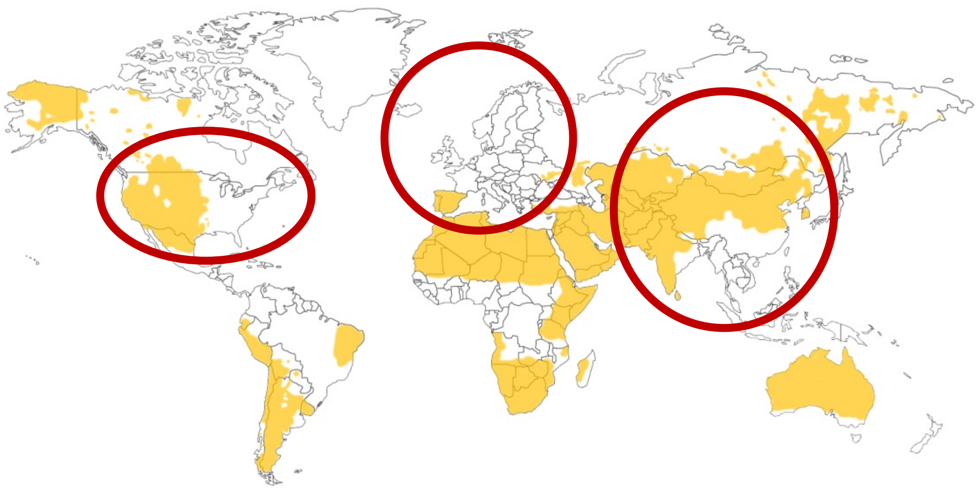
INCREASED HYDROLOGIC VARIABILITY

GREATEST IMPACT ON RELIABILITY OF WATER SUPPLY

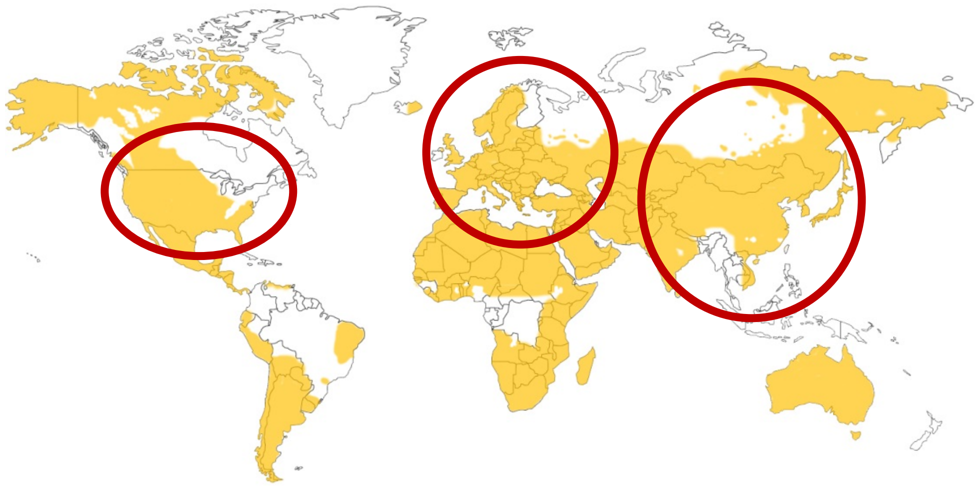
CLIMATE CHANGE

HOW MUCH WOULD VARIABILITY INCREASE

Current Conditions



Assume 25% Increase in Variability

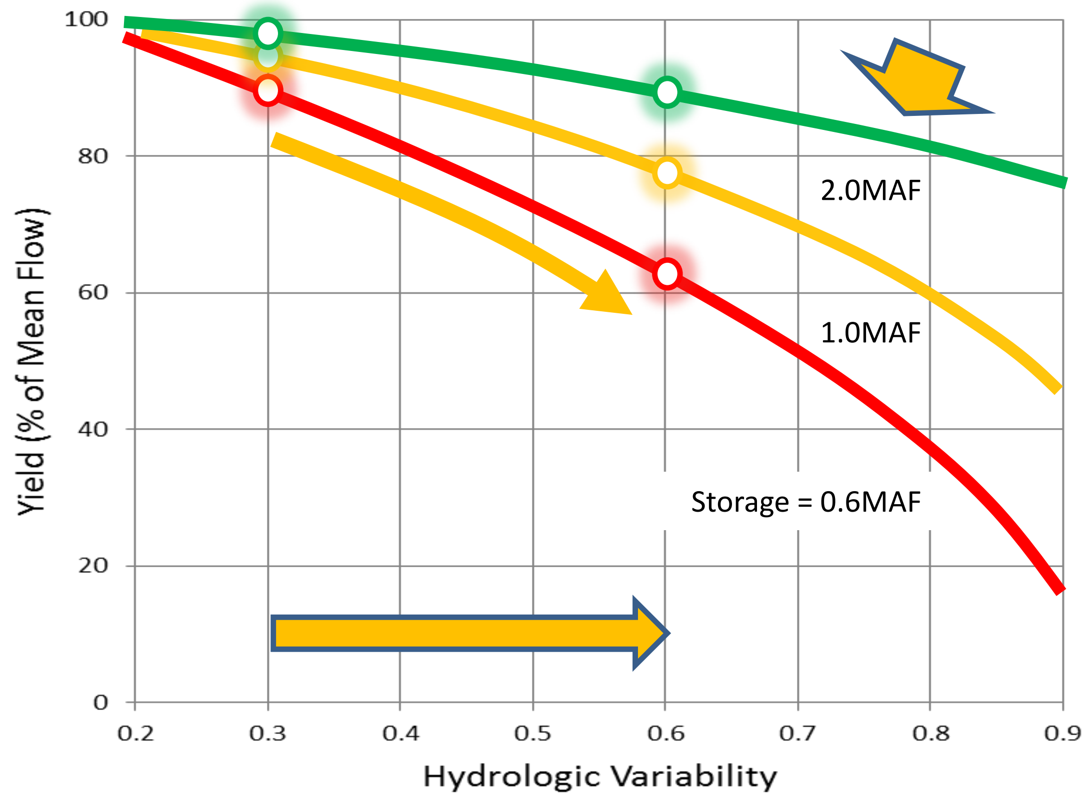


$$n_{crit} = \frac{z_\gamma^2 \cdot c_v^2}{4 \cdot (1-\alpha)^2}$$

HOW TO PREPARE FOR CLIMATE CHANGE:

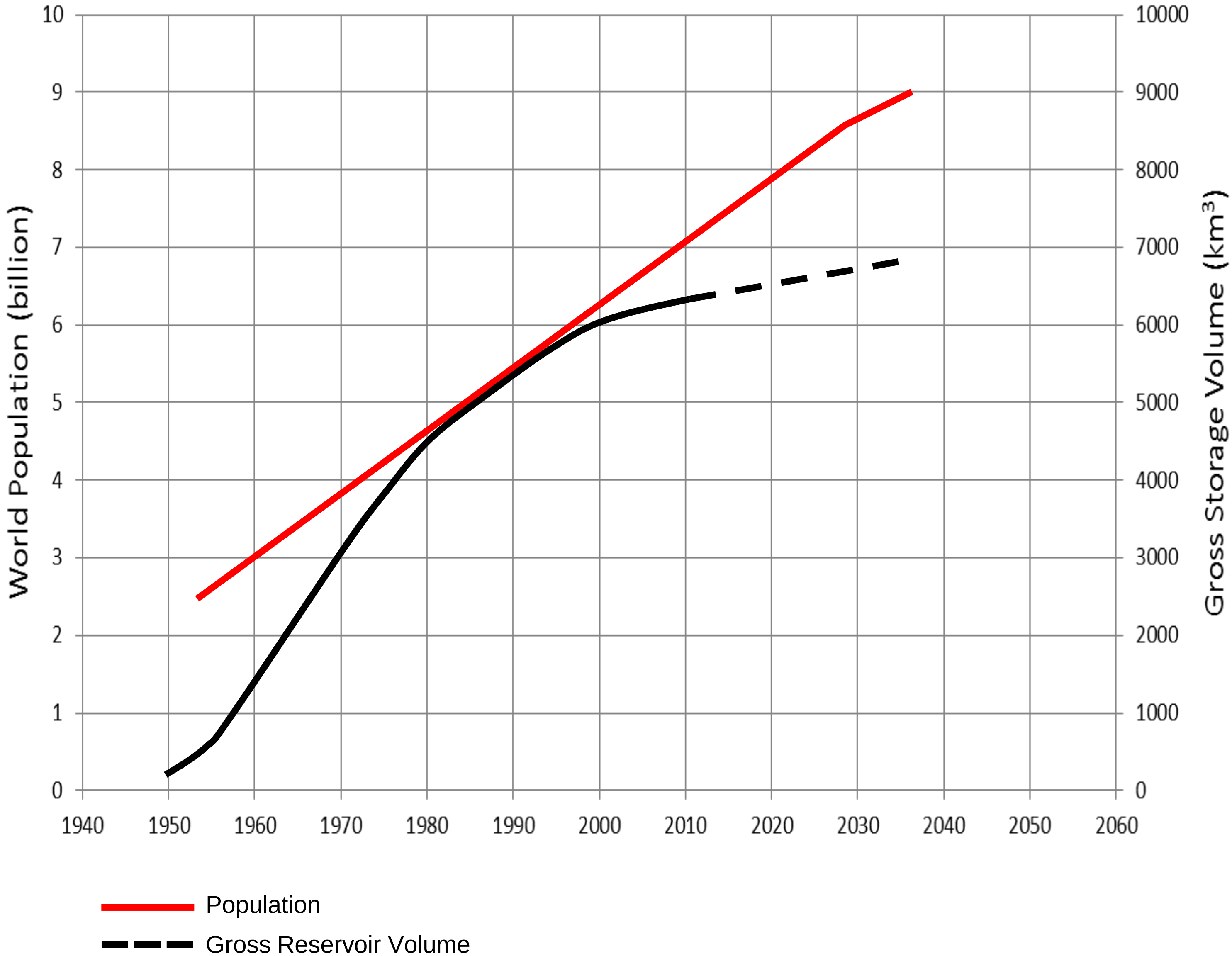
DESIGN, BUILD AND MAINTAIN ROBUST INFRASTRUCTURE

- Increased Hydrologic Variability due to Climate Change
- Reduction in Yield
- To Maintain Reliability of Water Supply
  - Hydrologically LARGE Reservoir Storage



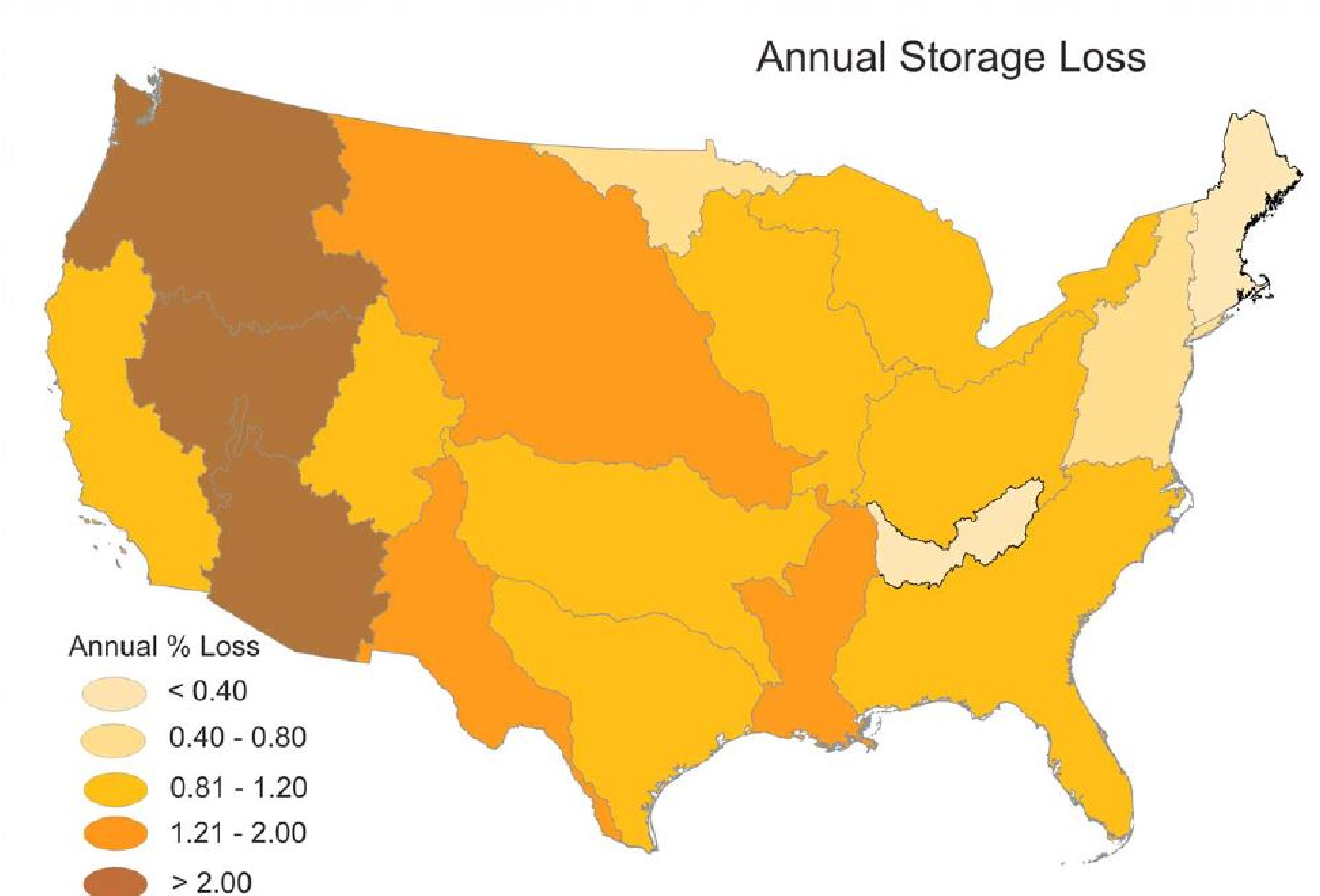
$$\alpha = 1 - \frac{z_{\gamma}^{2} \cdot c_{v}^{2}}{4 \cdot \tau}$$

GLOBAL POPULATION AND DAM CONSTRUCTION



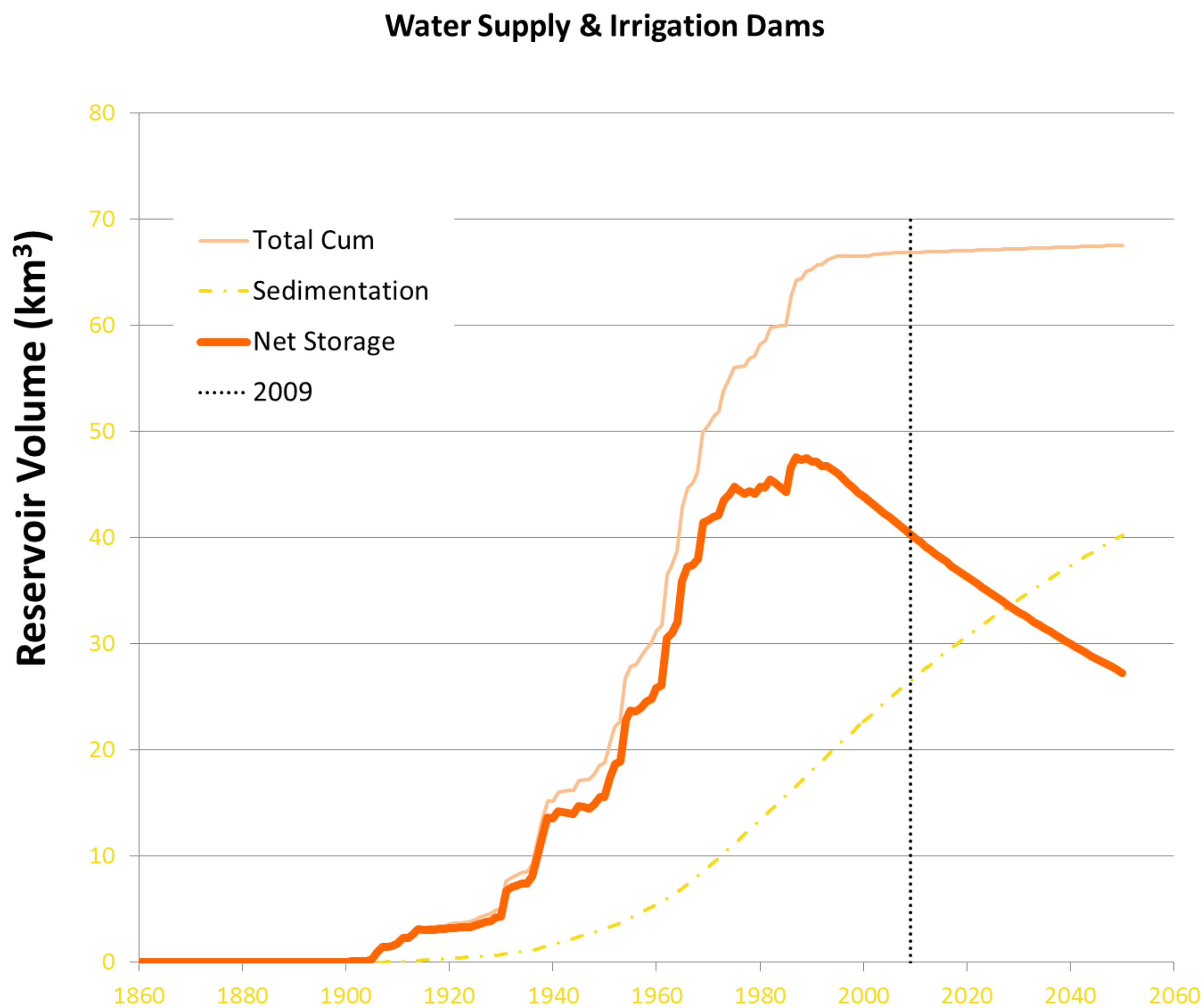
RESERVOIR SEDIMENTATION –
THE STORAGE SPACE ENEMY

STORAGE LOSS TO SEDIMENTATION

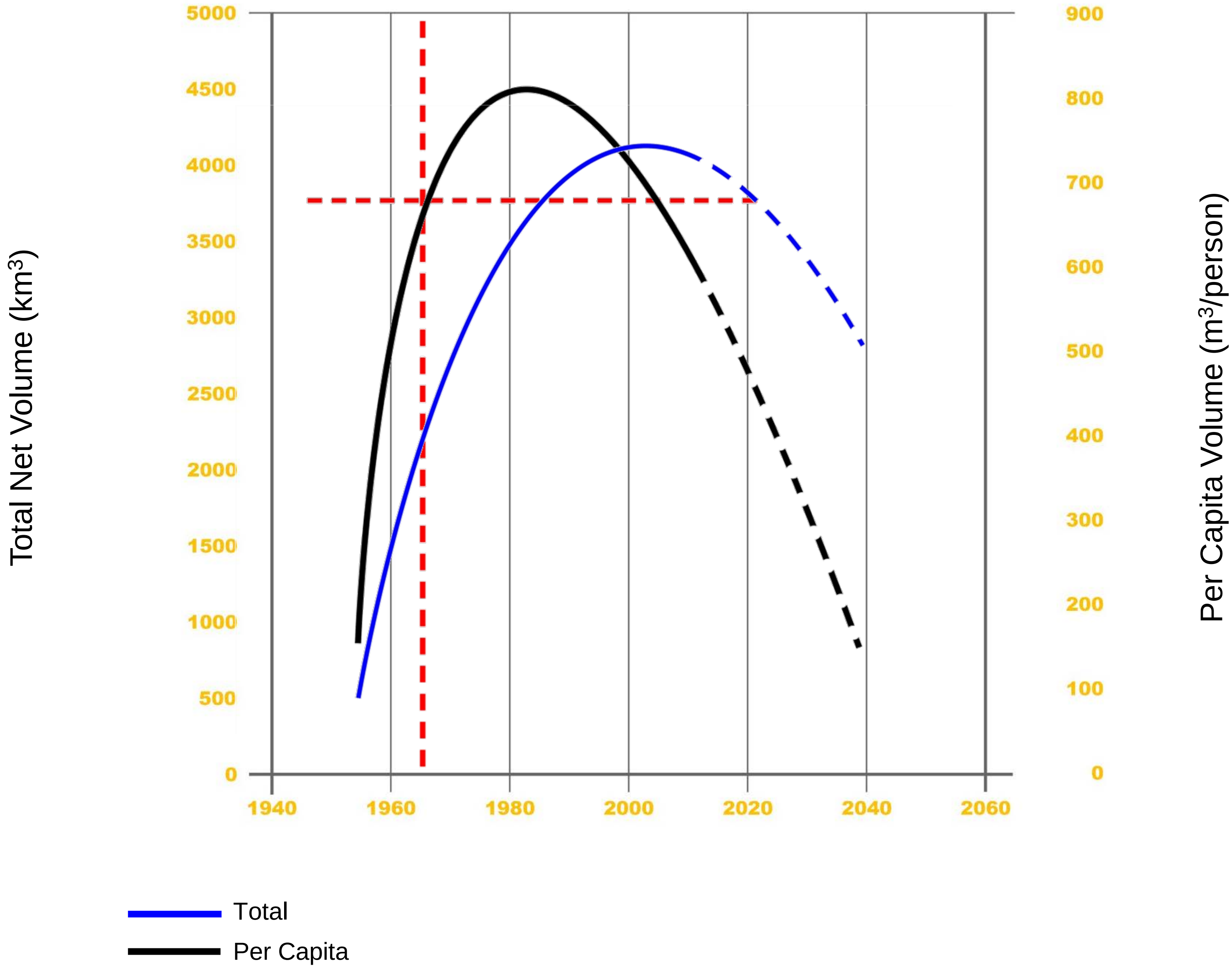


Graf et al. Sedimentation and Sustainability

NET STORAGE IN US DAMS

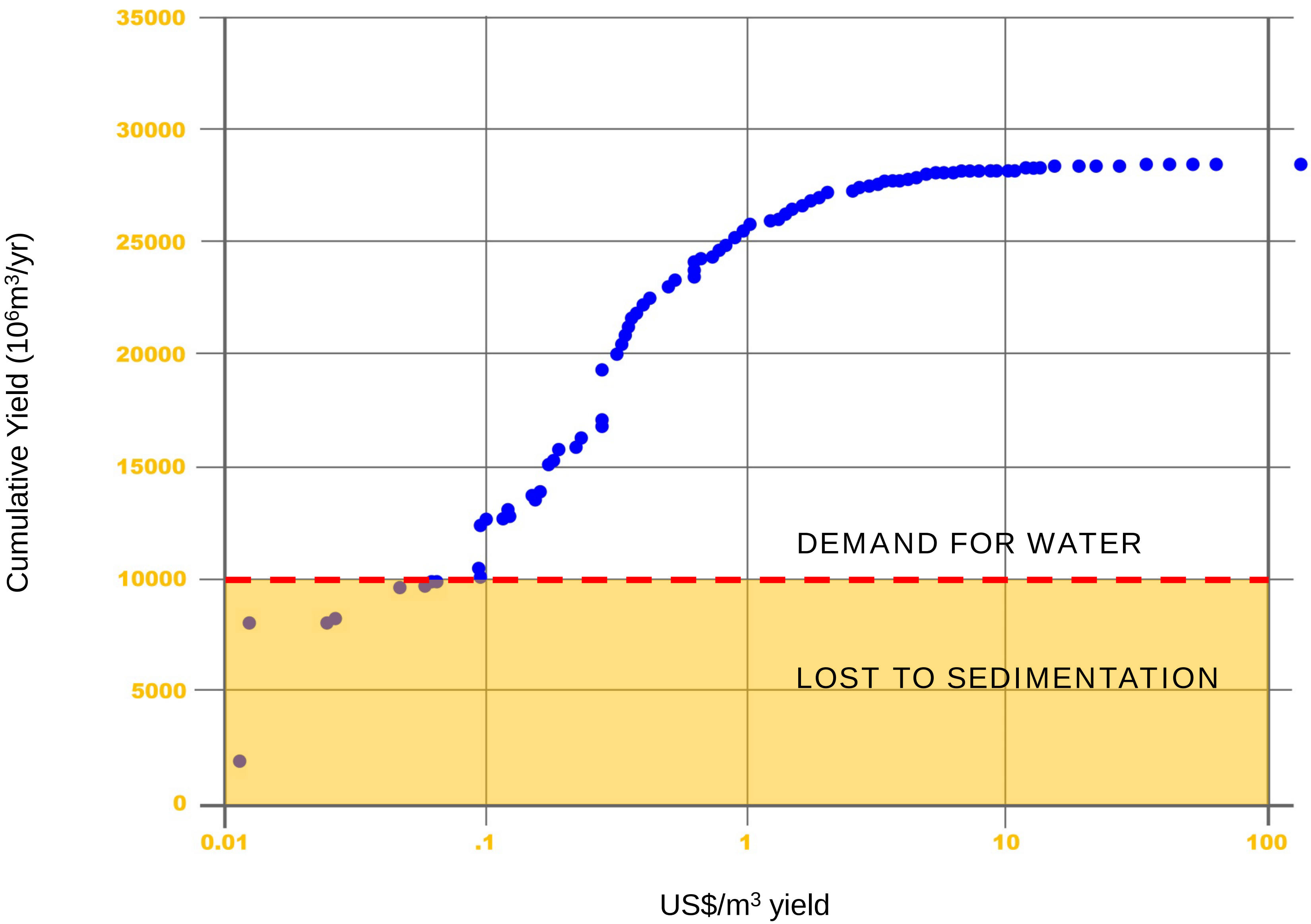


GLOBAL STORAGE IN LARGE DAMS



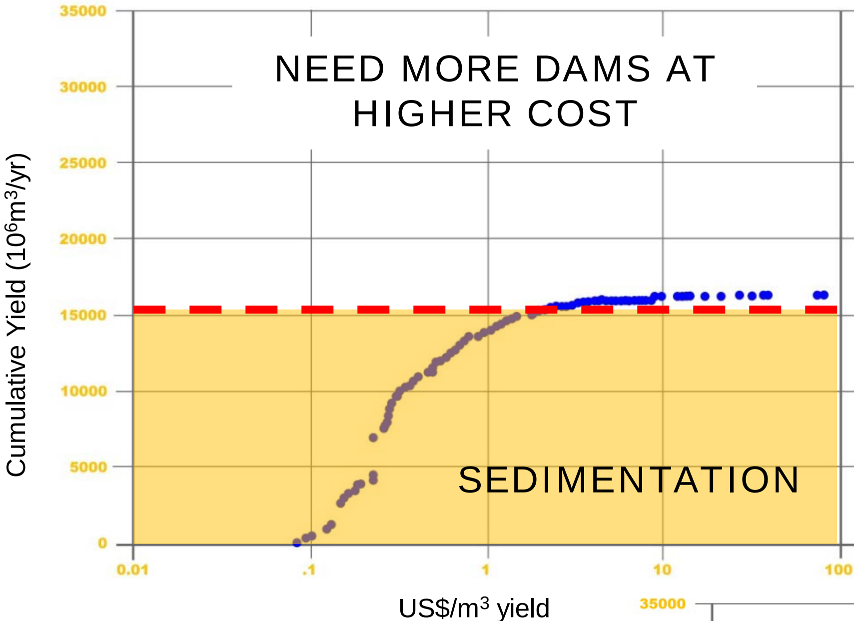
LIMITED NUMBER OF DAM SITES

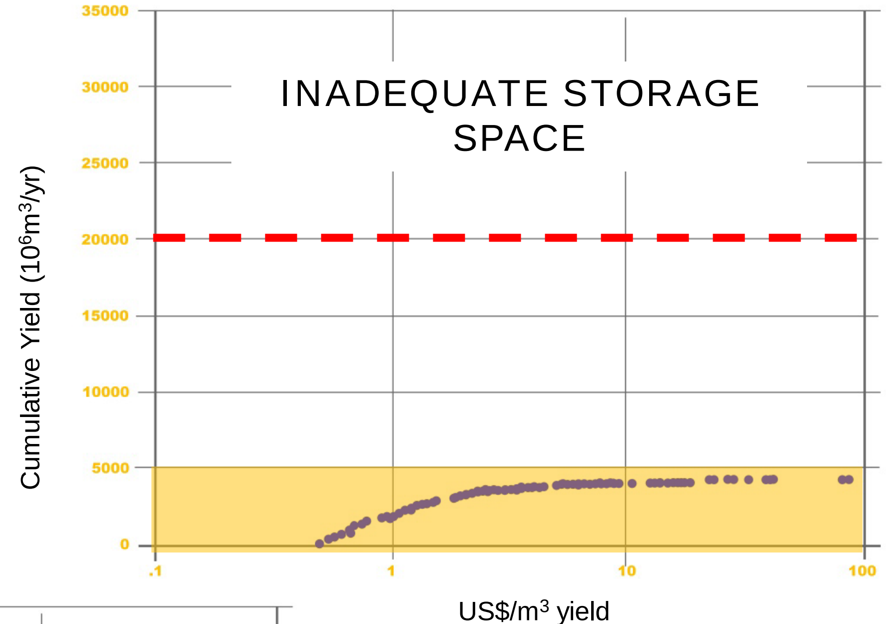
CONSEQUENCE OF CURRENT DEVELOPMENT POLICY

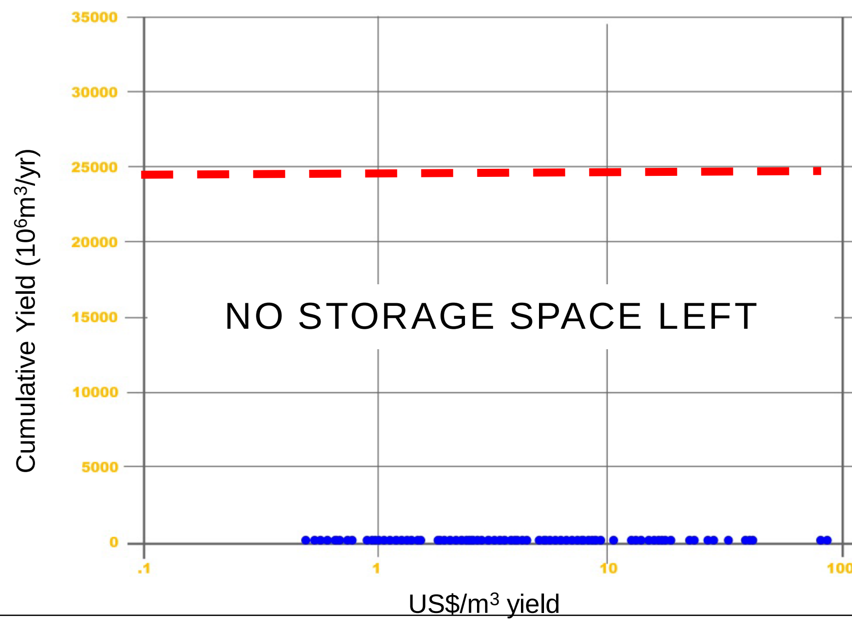


FUTURE GENERATIONS

CONSEQUENCE OF CURRENT DEVELOPMENT POLICY







MAKING THE RIGHT CHOICE

RESERVOIR SEDIMENTATION MANAGEMENT OPTIONS

Manage amount of sediment generated by the catchment

Upstream Management

- Check Dams
- Forestation

Allow sediment inflows to pass through or around the reservoir

Sediment Routing

- Sluicing
- Density Current Venting
- Bypass

Remove sediment which accumulates in the reservoir

Sediment Removal

- Dredging
- Excavation
- Hydro-suction
- Pressure Flushing
- Drawdown Flushing

DUAL NATURE OF RESERVOIR STORAGE

RENEWABLE OR EXHAUSTIBLE – A DELIBERATE CHOICE

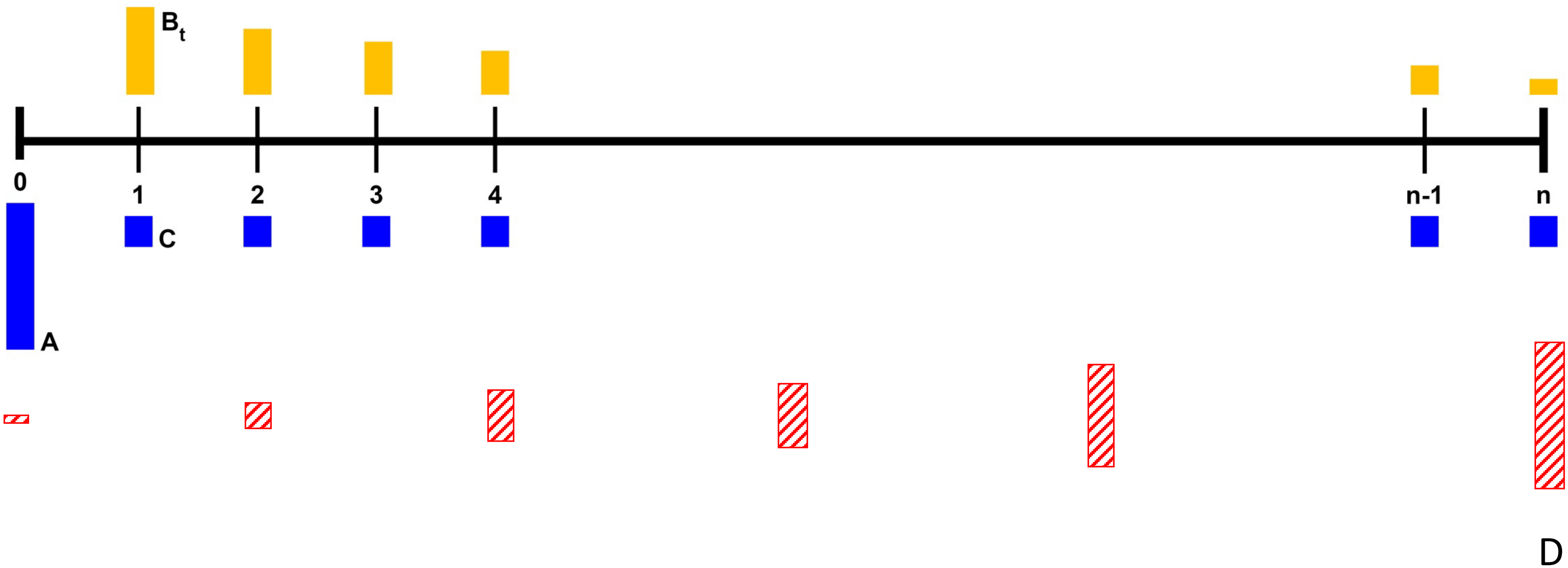
CURRENT ECONOMIC ANALYSIS APPROACH

$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t$$

$$d = \frac{1}{(1+r)}$$

CURRENT ECONOMIC ANALYSIS APPROACH

CONVENTIONAL REASONING FOR IGNORING LOSS



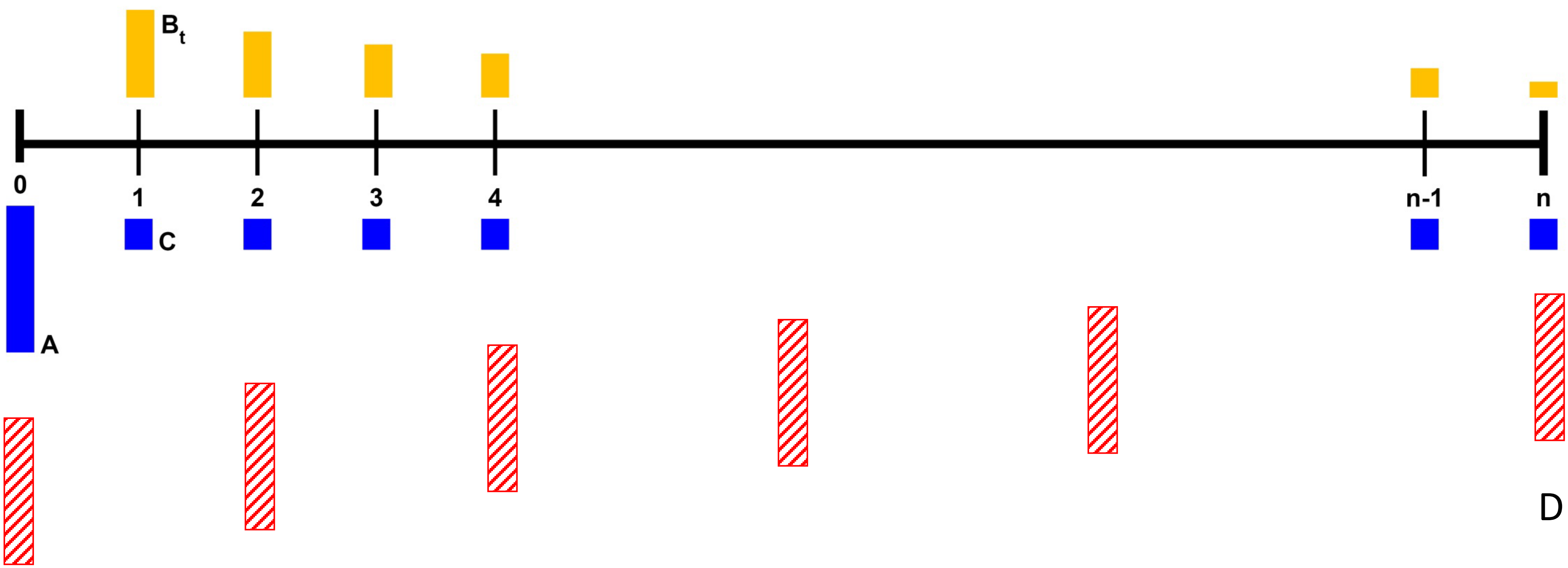
PV(D) <<< D

$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t$$

CORRECT ECONOMIC ANALYSIS APPROACH

HOTELLING PRINCIPLE

- Hotelling: Value of an Exhaustible Resource increases with the discount rate (i.e. Discounted value does not change)

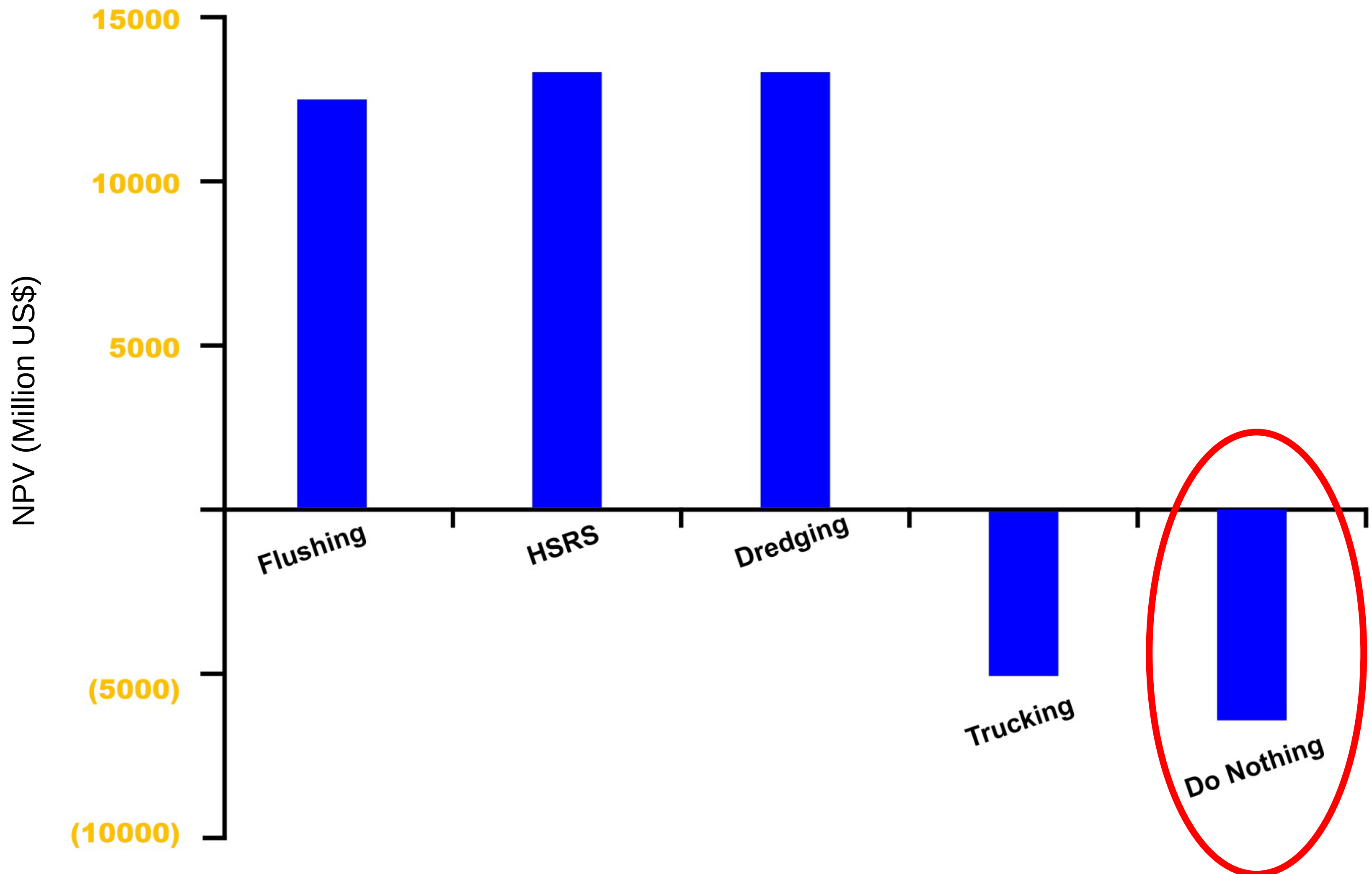


PV = D

$$NPV = \sum_{t=0}^{n} B_t \cdot d^t - A - \sum_{t=0}^{n} C \cdot d^t - D$$

ECONOMIC VIABILITY

HOTELLING PRINCIPLE



Example Project

DESIGN AND OPERATION

PARADIGM SHIFT REQUIRED

Planning & Design | Construction | O&M | Disposal

Conventional Design Life Approach

DESIGN AND OPERATION

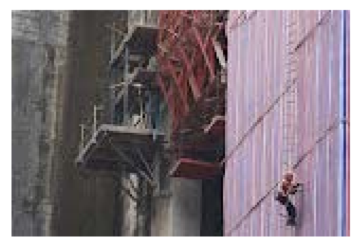
NEW PARADIGM

Planning & Design

Construction

O&M

Sediment Removal



Refurbishment

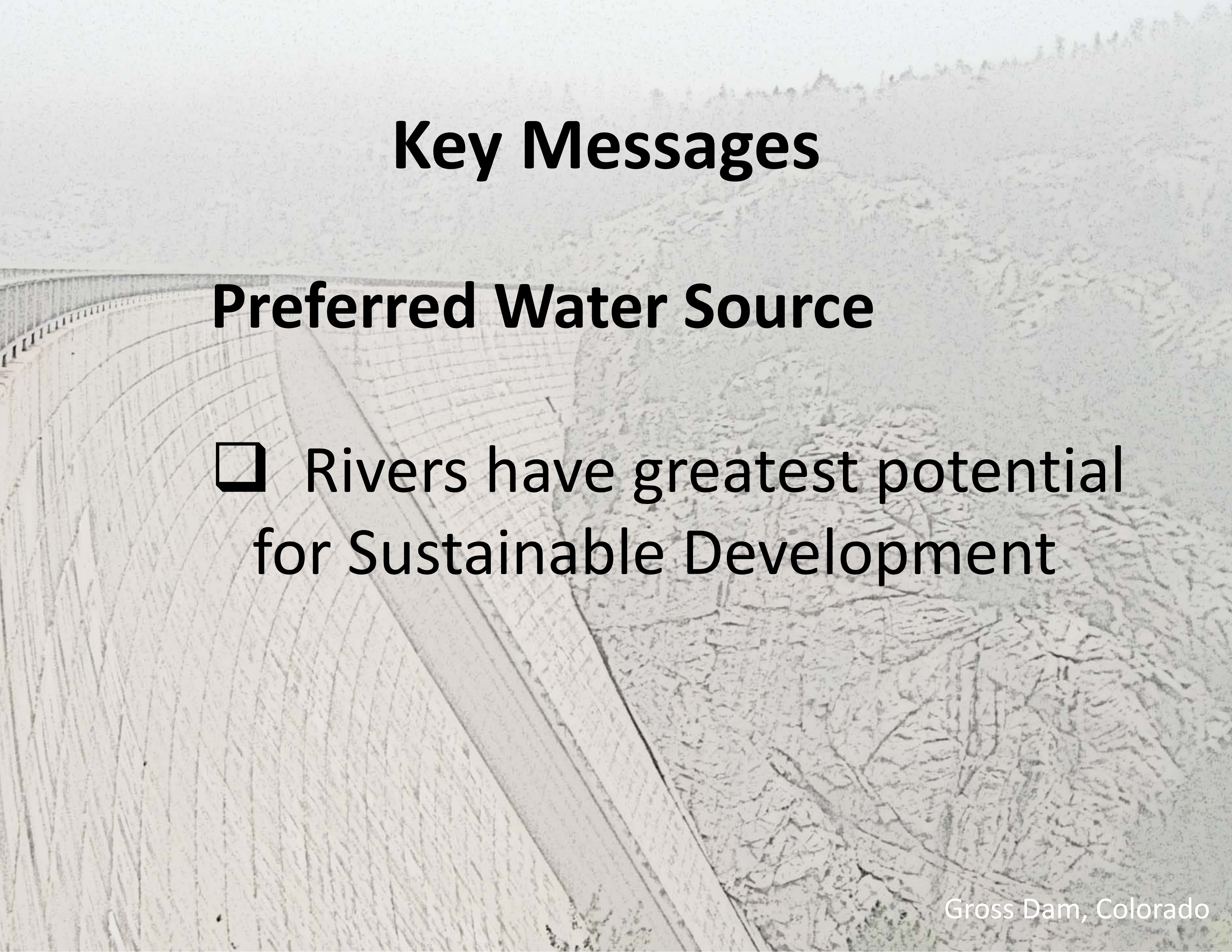
Preferred Approach: Life-Cycle Management Approach

Key Messages

Sustainable Development

- Create Intergenerational Equity
- Environmental Conservation
  - Desirable Consequence
  - Not the Objective

Gross Dam, Colorado


Key Messages
Preferred Water Source
❑ Rivers have greatest potential for Sustainable Development
Gross Dam, Colorado

Key Message

Climate Change Impacts

- ❑ Greater Need for Storage

Thika Dam, Kenya

Key Messages

Net Loss of Reservoir Storage Space

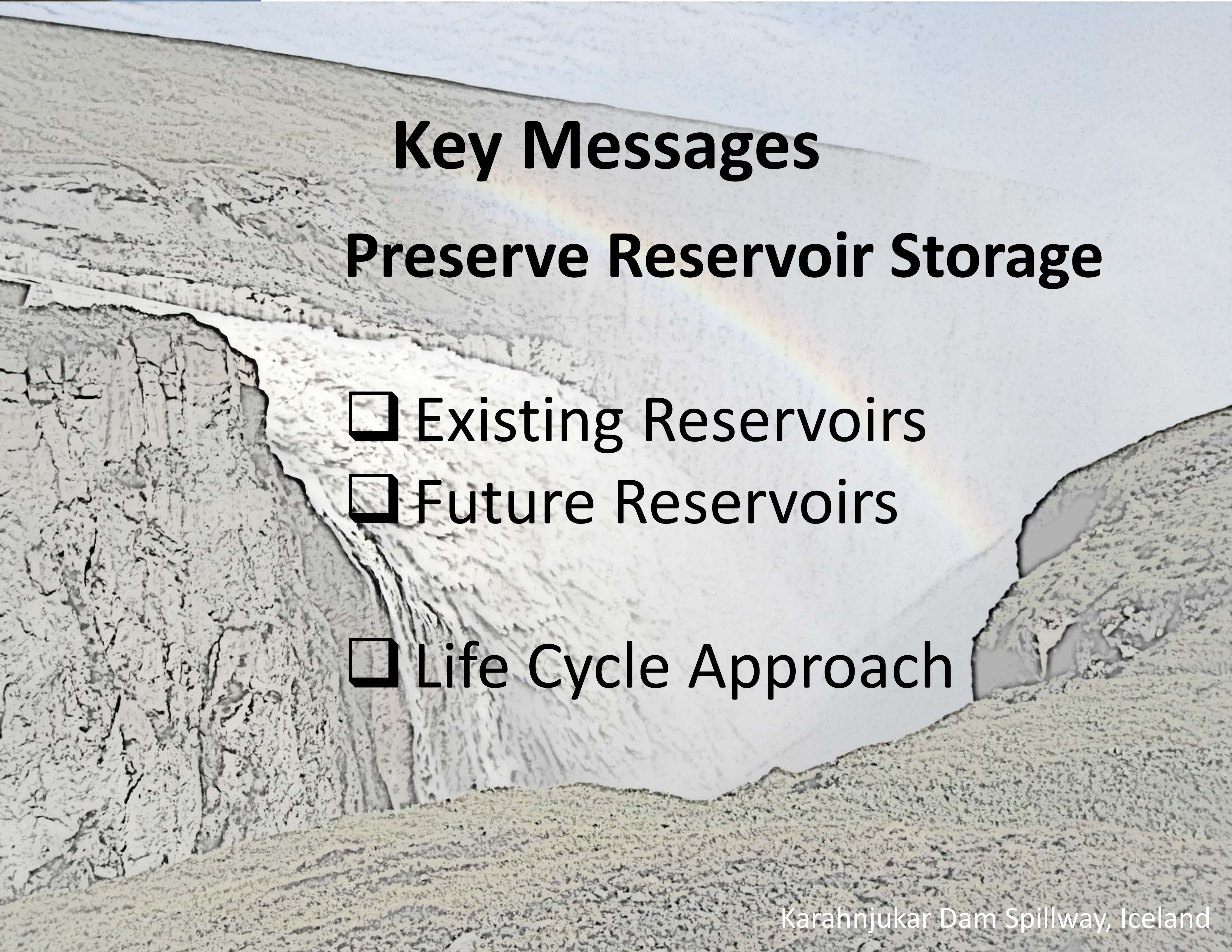
- ❑ Losing More Storage than Adding

Key Messages

Preserve Reservoir Storage

- ❑ Existing Reservoirs
- ❑ Future Reservoirs

- ❑ Life Cycle Approach



Karahnjukar Dam Spillway, Iceland

Key Messages

Feasibility of Sustainable Development

- ❑ Dual Nature of Storage
- ❑ Deliberate Choice by Designer
  - ❖ Exhaustible – Let Fill with Sediment
  - ❖ Renewable – Manage Sediment

- ❑ Economic Analysis Implications

Strontia Springs Dam, Colorado


ANTI-DAM SENTIMENT
JEOPARDIZES
OUR
COMMON FUTURE

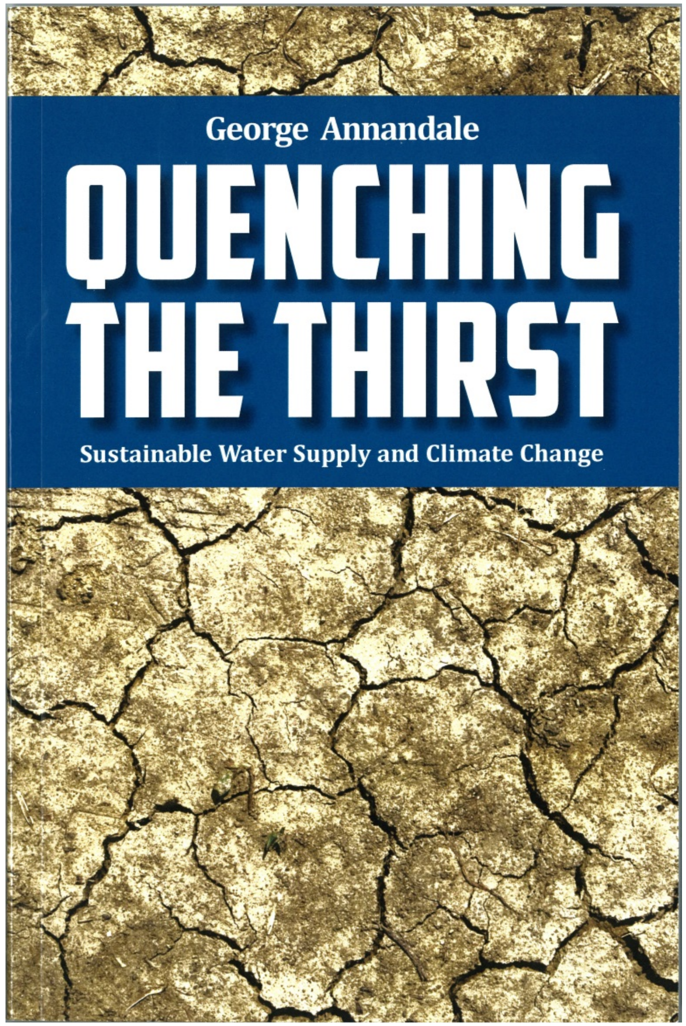
ENGINEERING LEADERSHIP

- Intergenerational Equity
- Reliability of Water Supply
- Climate Change
- Create and Preserve Reservoir Storage

- Be the Voice of Reason

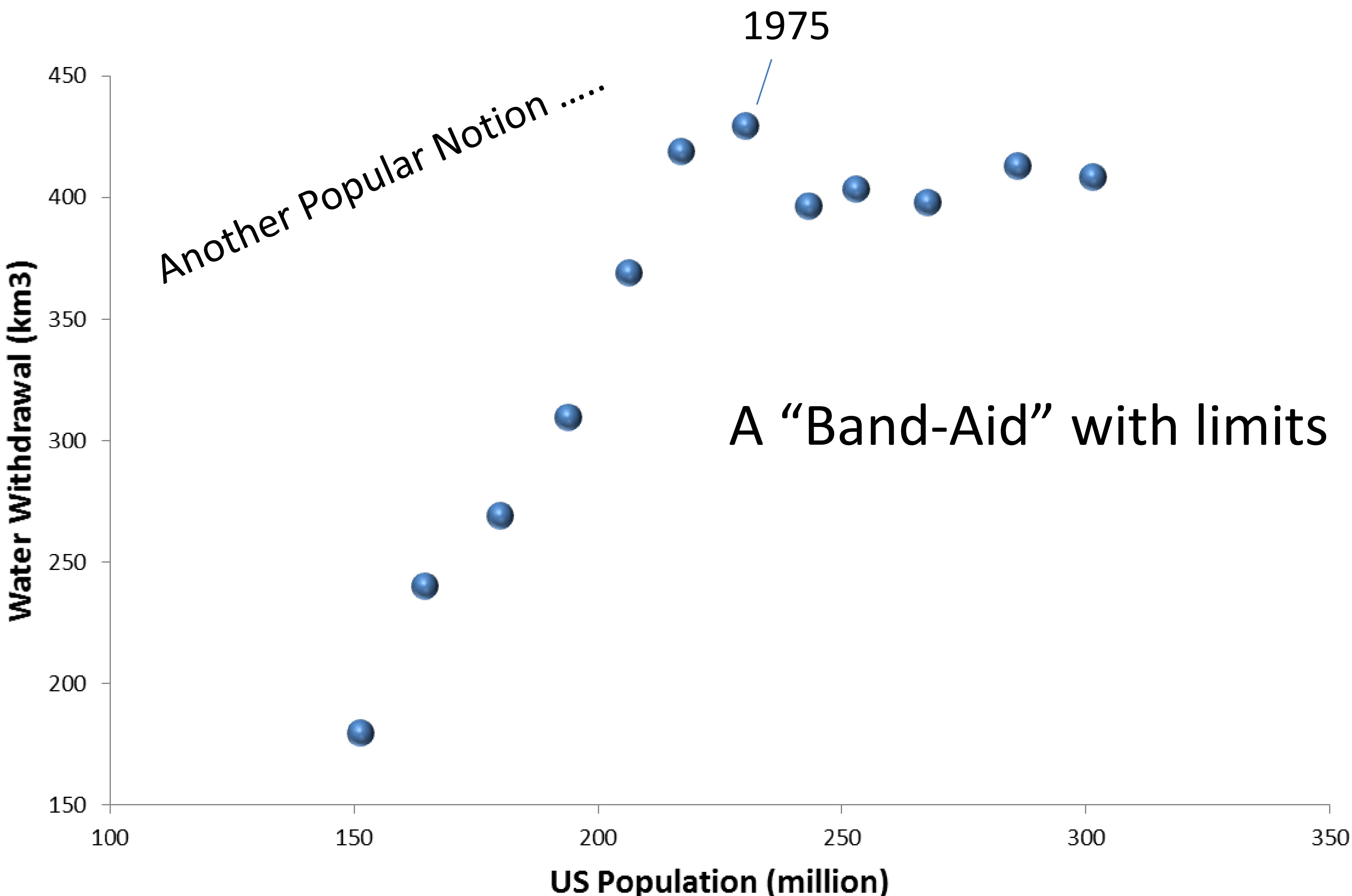
John Briscoe
World Bank Engineer
Dams Advocate
Deceased 2014

REFERENCE



Annandale, G. 2013. Quenching the Thirst – Sustainable Water Supply and Climate Change, CreateSpace, Charleston, SC

REMOVE DAMS – CONSERVE WATER
WATER CONSERVATION IN THE US



USGS Data

WORLDWIDE WATER CONVERSATION

NOT THE MAGIC BULLET